16x2.5 Gbit/s Downstream Transmission in Colorless WDM-PON based on Injection-Locked Fabry-Perot Laser Diode using a single Quantum Dash mode-locked Fabry-Perot laser as multi-wavelength seeding source

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Abstract: Error-free colorless WDM-PON downstream over 25 km for 16 channels with 85 GHz channel spacing is experimentally demonstrated at 2.5 Gbit/s, using an injection-locked Fabry-Perot laser and a quantum dash mode-locked laser as a coherent seeding source.

OCIS codes: (060.2330) Fiber optics communications; (140.3460) Lasers

1. Introduction

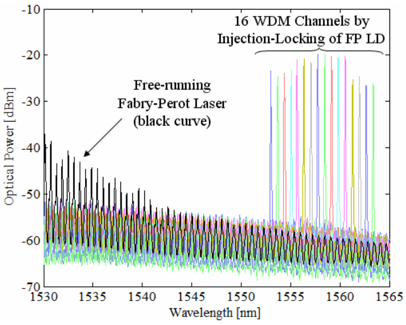
The demand for high bit-rate access networks rapidly grows due to the increase of broadband services. To supply with such a bandwidth demand, the wavelength division multiplexed passive optical network (WDM-PON), in which each wavelength is dedicated to a single subscriber, appears as the ultimate solution in terms of its very large capacity [1]. However, the bandwidth requirement increases the cost of emission and reception components. In order to increase the bandwidth of future WDM-PON systems while maintaining the cost-effective optical components, recent research in access network has been proposed various solutions. For the downstream transmission in WDM-PON, a typically low-cost solution is based on spectrum-sliced injection-locked Fabry-Perot lasers (Il-FP) [2], [3], or on reflective SOA [4] but the performance is limited at 1.25 Gbit/s due to important intensity noise. Another solution using coherent source (such as directly modulated DFB or injection-locking using a DFB as seeding source) has been proposed [5], but the wavelength management in this case is more complicated because of non-colorless operation, and furthermore, this solution is not really low-cost.

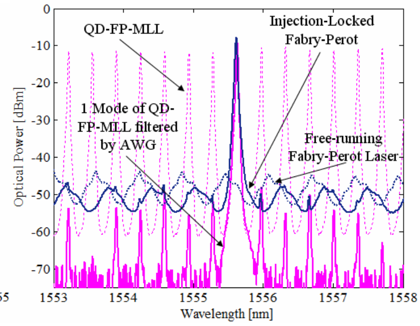
In this paper, we propose for the first time to our knowledge and in the framework of the French ANR project Antares, a novel technique for optical transmitters in colorless WDM-PON system using a polarization insensitive IL-FP laser directly modulated at 2.5Gbit/s as the cost-effective and robustness solutions. The principle of this technique is based on a single low-noise quantum dash Fabry-Perot mode-locked laser (QD-FP-MLL) combined with an array waveguide grating (AWG) to provide the multi-wavelength coherent seeding source for injection-locking. The feasibility of such a system used for the transmission of 16 WDM channels in the C-band over 25km SMF fiber is assessed in this paper. A performance comparison between this solution and the case of injection-locking by a tunable source was performed.

2. Laser characteristics

Generally, coherent injection-locking of conventional Fabry-Perot laser diode (FP LD) strongly depends on the polarization state of the injected signal, because conventional FP LD operates mainly on TE mode as the gain is more important for TE fields, what leads to a better sensitivity. To overcome this polarization dependence, the studied IL-FP laser is especially designed so that the laser operates on both TE and TM modes, and furthermore, the optical spectra of two mode lines TE and TM are superimposed in the working wavelength range. These conditions have been achieved by using a polarization-insensitive (PIS) gain material as the gain section and a strained InGaAs material in the second section to compensate for birefringence [6]. This section is polarized by a current $I_{Polarization}$ to maximize the superposition of the two mode lines TE and TM. The typical value of $I_{Polarization}$ to achieve such a state is around 100 mA, for which a quasi-superposition of the two mode lines is obtained in the range of 1545nm to 1565 nm.

The optical spectra at the output of FP laser diode without injection and with injection of different individual mode of QD-FP-MLL filtered by an AWG channel are shown on fig 1 and 2. The measurements of Relative Intensity Noise (RIN) are presented on Fig 3. One of the most attractive characteristics of QD-FP-MLL is its very low RIN, lower than -150 dBc/Hz in the figure. However, each individual mode of the QD-FP-MLL has a RIN level higher than that all modes together. Nevertheless we find that an important noise reduction is obtained by injection-locking when comparing the noise spectrum of IL-FP to the free-running FP LD's one. The IL-FP in this measurement is injected by -4 dBm at 1555.64 nm. The IL-FP presents a RIN level around -135 dBc/Hz and the limitation by the relaxation frequency at 3 GHz is avoided.





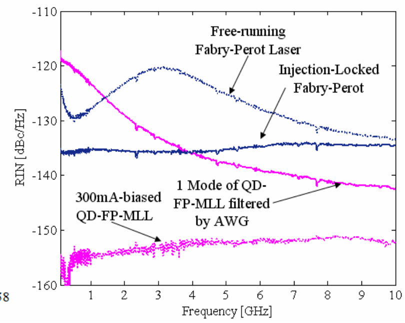


Fig. 1. Optical spectra of 16 WDM channels Fig. 2. Optical spectra zoomed on one channel Fig. 3. Relative intensity noise spectra

3. Experimental demonstration in a WDM-PON configuration

Fig. 4 presents the experimental setup used for colorless WDM-PON downstream transmission based on an IL-FP laser diode. In the Central Office, a 300mA-biased QD-FP-MLL [7] with 42.5 GHz mode spacing is used to provide the multiple wavelength seeding source. The optical power at its output is around +5 dBm. It is then amplified via an erbium doped fiber amplifier (EDFA) with an output power of 17 dBm in order to reach a sufficient level necessary for FP-LD injection-locking operations. This signal then passes through a circulator and a commercial tunable AWG whose channel grid is adjusted to coincide with the QD-FP-MLL modes. The channel spacing is set at 85 GHz (twice as QD-FP-MLL mode spacing, so that one mode out of two is thus selected by the AWG). For practical application of such a system, the QD-FP-MLL could be designed and optimized (the cavity length mainly) so that their modes match the ITU (D)WDM channel grids.

One mode of QD-FP-MLL selected by the AWG is injected into the Fabry-Perot laser biased at 62 mA (I_{Gain}). The optical power of at the input of IL-FP is around -5 dBm and the side-mode-suppression-ratio (SMSR) is typically 38 dB. The IL-FP has +1dBm output power and a SMSR about 33 dB. The IL-FP is directly modulated via the gain section by a 2Vpp amplitude 2^{15}-1 PRBS at 2.5 Gbit/s. Finally, the modulated optical signal passes through the AWG on the same channel and then in the circulator before propagating in the optical fiber towards the ONU.

The transmission length is 25 km including 20 km of feeder fiber and 5km of distribution fiber. The used fiber is standard singlemode fiber (SMF) without chromatic dispersion compensation. A second tunable AWG which connects the two sections of fibers is used to separate different WDM channels (the remote node in the optical access architecture). This second tunable AWG must be adjusted to the same parameters as for the first one. At the ONU, the modulated optical signal is directly detected by a commercial PIN receiver at 2.5 Gbit/s. A 10/90 coupler is used so that a portion of the optical signal is sent to the monitoring system including a power meter, an optical spectrum analyzer and a sampling oscilloscope. The signal of the PIN receiver is sent to the error detector to evaluate the transmission performance of the system. As the tunable AWG presents an insertion loss of nearly 7 dB and the circulator presents an insertion loss of 1 dB, the total budget of the proposed system is about 20 dB. (reached with a PIN at the reception block).

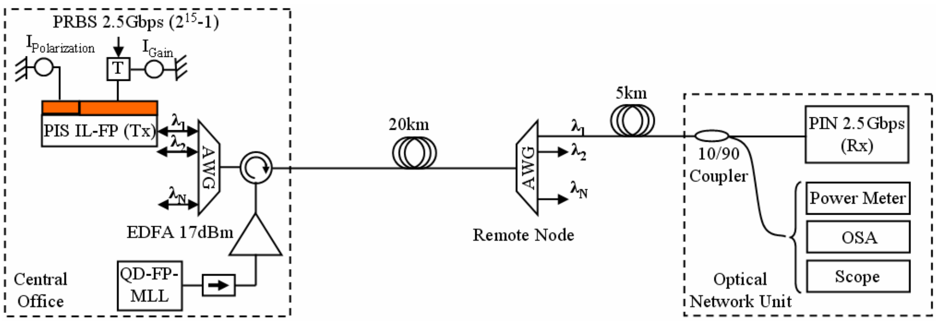


Fig. 4. Colorless WDM-PON downstream transmission using IL-FP LD with a QD-FP-ML laser for multi-λ seeding source

Fig 5 shows measured bit-error-rate (BER) versus received optical power for Back-to-Back (BTB) and for downstream transmission over 25 km SMF. These measurements have been done with two types of injected sources: The first one is a commercial tunable laser and the second one is the QD-FP-MLL. Since the performance of IL-FP strongly depends on the injection conditions, both have been measured with the same conditions: -6 dBm injected power at 1555.64 nm. We find that the transmission performances with both optical sources are practically the same: The receiver sensitivity at 10^{-9} is -22.5 dBm in BTB configuration and a power penalty less than 0.5 dB at this BER has been measured after 25km downstream transmission. Compared to a 2.5

Gbit/s $LiNbO_3$ modulator, a power penalty of 2 dB has been measured for the BTB configuration. This power penalty is due to the extinction ratio of the $LiNbO_3$ modulator which is higher than the IL-FP's one.

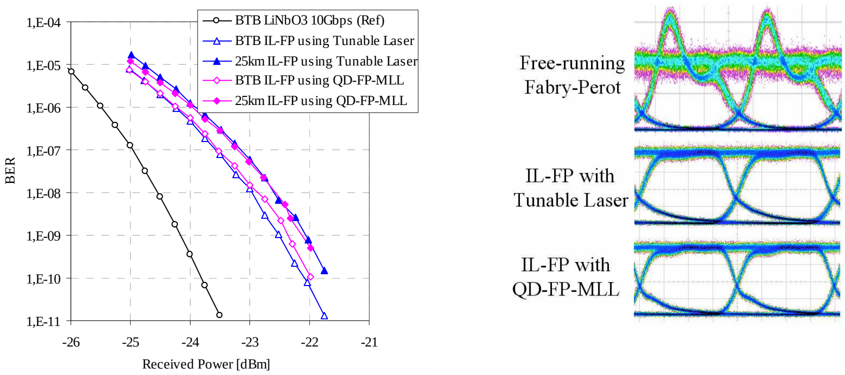


Fig. 5. BER measurements for BTB and for downstream transmission over 25km SMF

On the eye diagrams on the same figure, we clearly observe the noise reduction on level "1" by injection-locking and the relaxation frequency at 3 GHz in the free-running case completely disappears in case of injection-locking.

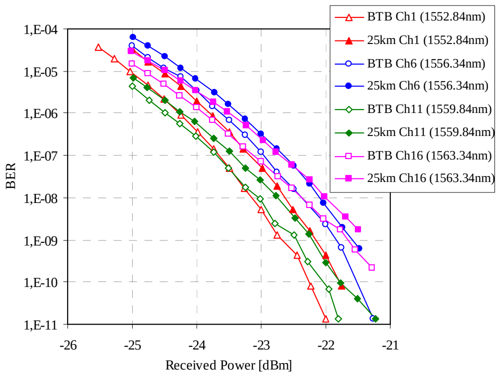


Fig.6. BER measurements of 4 channels

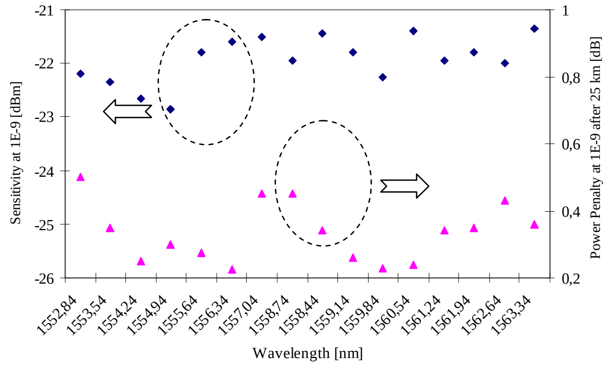


Fig. 7. Receiver sensitivity and power penalty at 10^{-9} of 16 channels for 25km

Fig. 6 shows BER measurements versus received power for 4 channels in the WDM-PON configuration as described in fig. 4. Error-free transmission is achieved for all of these channels and a maximal power penalty of 0.5 dB is also obtained after transmission over 25 km. The receiver sensitivities and the power penalties after 25 km transmission at 10^{-9} of 16 channels are presented on Fig 7. The measured receiver sensitivity at 10^{-9} for 16 channels covers from -23 dBm to -21 dBm and has an average value of -21.9 dBm on a wavelength range of 12 nm. The measured power penalty at 10^{-9} is less than 0.5 dB after 25 km transmission compared to BTB configuration.

4. Conclusion and perspectives

We experimentally demonstrated for the first time the feasibility of using a single QD-FP-MLL as a multi-wavelength coherent seeding source for colorless WDM-PON system based on polarization insensitive IL-FP LD. Error-free transmission at 2.5 Gbit/s was achieved over 25 km of SMF for 16 channels with 85 GHz spacing in the C-band. An average sensitivity at 10^{-9} of -21.9 dBm and a power penalty less than 0.5 dB were achieved for all channels. This solution also could be applied for upstream transmission in WDM-PON (colorless ONU) but requires a more important optical budget. Finally, with a QD-FP-MLL whose mode spacing is compatible with ITU grids, the proposed solution is very promising for the future WDM-PON system with the cost-effective and high performance optical transmitters.

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